

Aerodynamic enhancement of formula car by addition of different combination of accessories and analysing the effect

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ABSTRACT

Formula one sport is one of the best racing sports in all. In modern days there are modern ways to create a car almost fast as an aircraft. In this racing sport, aerodynamics is playing the most important role in achieving faster speed than any other cars. In order to achieve maximum efficiency and better speed, researchers spend a lot of money in the field of modern technology. In the path of best, the researcher got their attention to the aerodynamic structure of the car. So, researchers are working on multiple points to make formula cars faster than any cars and for this they make every possible change in a car's body to make it aerodynamically better. The researchers were concerned about the following points while making a design of the car-(1.) Creation of enough downforce so car body will be pushed onto the track for better grip and faster corner speeds. (2.) To reduce the drag. (3.) To make it aerodynamically better to increase the speed. In this project, there will be an analysis of the car to calculate drag force and downforce to see the effect of downforce on speed and traction, by which researchers can determine which body part of the formula car will be modified to make the car faster and more efficient. Here different models have been analysed with the combination of different accessories and the effect of each additional part have been studied.

Key words: Aerodynamic analysis, Downforce, Drag, Traction, Computational fluid dynamic analysis

I. INTRODUCTION

A formula one race is the world's prestigious motor race and for single-seater cars, it is the highest class of international racing. Here the word formula in the name refers to the set of rules and parameters that must be confirmed for the qualification in the race. Here the car is of open-wheel, single-seater, and open cockpit type. Every year companies spent hundreds of millions of dollars just on the designing process of a car, and in which the most complex and important design is in the aerodynamic structure of the car. Just to shave some milliseconds off from the lap times a whole lot of money and time is being invested by companies. With the change in time, tracks getting shorter and the circuits more complex. Nowadays the limiting factor for the performance of a racing car is its acceleration rather than its top speed. As the circuits are becoming more complex if a car could accelerate quicker, change direction faster, can take sharper turns quicker, and brake harder then it will increase its average speed over a single lap hence less lap time. Therefore, the primary focus had shifted to downforce generation from drag reduction. In formula one race, aerodynamics is an integral factor in a car's performance and is constantly being improved just to increase downforce. Downforce is also known as negative lift or downward force exerted due to inverted aerofoil shape by passing air. It is being increased constantly by improving aerodynamic design in various ways for better stability and faster corner turns. Downforce is also important because we get more stability and traction by increasing weight but without increasing the mass of the vehicle. To improve this characteristic various add-on being added. Our main aim in aerodynamics design is to reduce drag and lift and increase downforce. But the lift and drag force are inversely proportional to each other, if one uses the front wing to reduce lift, it comes at the expense of an increase in drag force as more area will be exposed to incoming air. In fig.1 creation of downforce is shown on the inverted aerofoil.

Many components are added to improve the aerodynamic characteristics and it is a must to consider that there should be

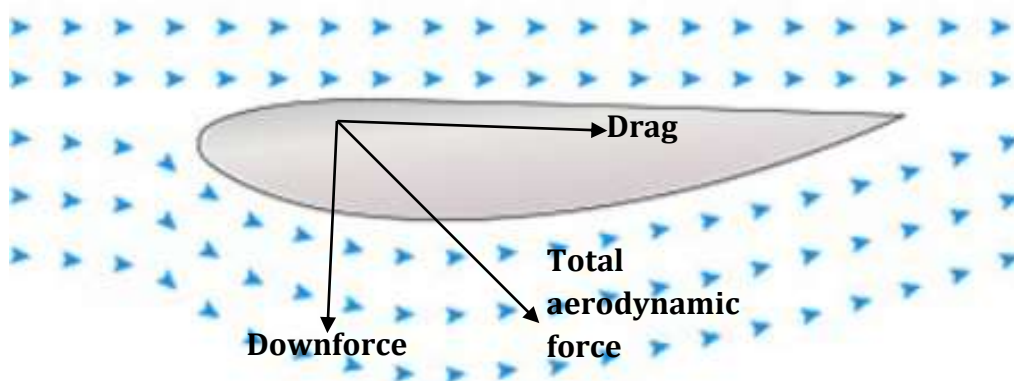


Fig.1 Inverted aerofoil

the right combination of add-ons or instead of the creation of downforce, drag will be increased drastically.

There are four components that are majorly responsible for the generation of downforce.

- a. Front wing
- b. Rear wing
- c. Diffusors
- d. Underfloor



Fig.2 Front Wing



Fig.3 Rear Wing

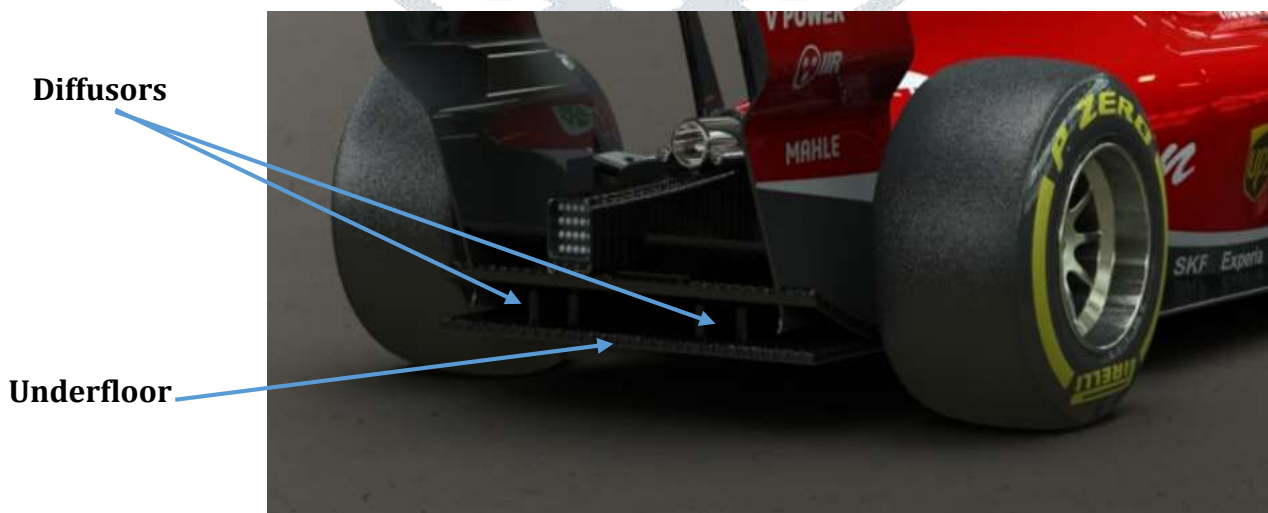


Fig.4 Underfloor and diffusers

Generally front and rear wings individually, account for 25% of the downforce, and underfloor and diffusers combined account for 50% of the downforce. Every part of the formula one car is designed to work in conjunction with each other and the problem for any part is handled by the other. Therefore, the combination should be established as such that evenly distribution of aerodynamic forces between all four tires and the center of the pressure should act behind the center of gravity. Generally, formula one cars are mid-engine cars therefore, at the rear, a greater proportion of the downforce is desirable.

Different add-ons and their detailed functions that how they improve the aerodynamic design have been explained in

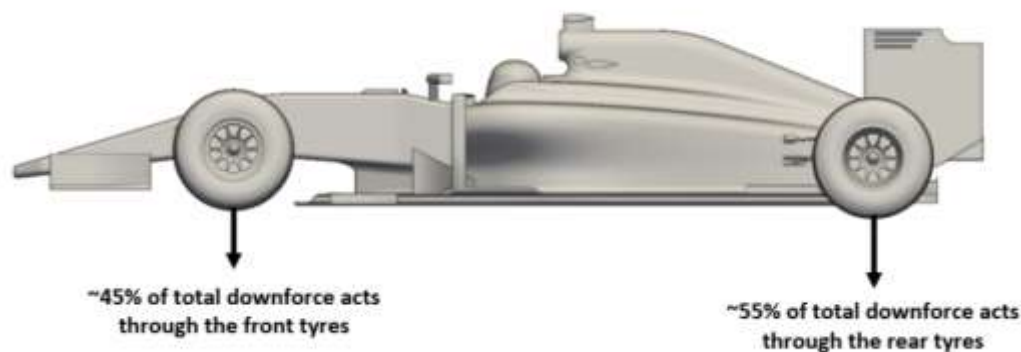


Fig.5 Distribution of downforce

detail in section 2.

Car specifications

Table 1. Engine Specification

Configuration	Ferrari 062 EVO
Location	Mid-engine, longitudinally-mounted, rear-wheel drive
Construction	Aluminum block and head
Displacement	1600cc V6 turbocharged
Valve	4 valves/per cylinder, DOHC
Aspiration	Turbo
Fuel feed	Direct fuel injection

Table 2. Dimensions of the car

Weight	733 kg
Length	5000 mm
Width	2000 mm
Height	950 mm
Front track width	1600 mm
Rear track width	1550 mm
Wheelbase	3621 mm

II. DESIGN AND ANALYSIS PROCESS

Here Ferrari SF71H model is used for our design reference and the dimensions were taken arbitrarily. The whole design of the CAD model and analysis processes were performed on Solidworks 2020. Here steady-state external aerodynamic analysis has been performed and three different cases were taken (i) Baseline model without any add-ons (ii) Baseline model with the front wing, nose wing, ear wing, top exit, and roof spoiler (iii) Model attached with all add-ons including front wing, rear wing, nose wing, barge board, ear wing, roof spoiler, top exit, underfloor, and diffuser. These all-different models were analyzed at six different speeds and it was tried to observe the differences in the generation of drag and downforces. The isometric view of the baseline CAD model is shown in fig.6.

The next move will be gradually adding the different parts and analyzing the model for different speeds. Here it was divided into three steps and at every step, it was being observed that a particular set of parts like a front wing with nose

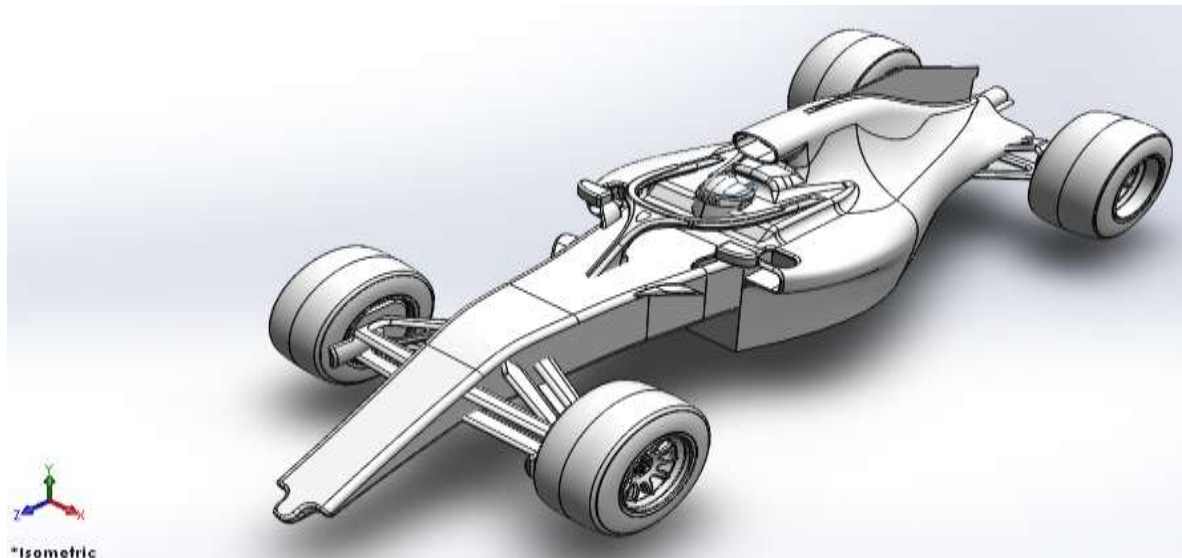


Fig.6 Baseline model without any add-ons

wing, ear wing, roof spoiler, and top exit will affect the performance in terms of drag and downforce. The different add-ons that will be added are discussed in detail below.

Rear wing: This is the combination of three cascaded inverted aerofoil wings supported by endplates. It is responsible for approximately 25% - 30% of the overall downforce. As the main purpose of this wing is to create downforce and to throw the dirty air coming through the car's body upward. In this rear wing, two inverted aerofoils are cascaded together and one is attached in the lower portion to throw lower air streams upward. Due to this rear wing more area is exposed to moving air which will increase drag but the creation of downforce is much more than that.

To get the advantage of straight tracks DRS (drag reduction system) system is introduced which gives control to the driver so that they can lower their rear wings to make them straight which lowers the drag and hence boosts the top

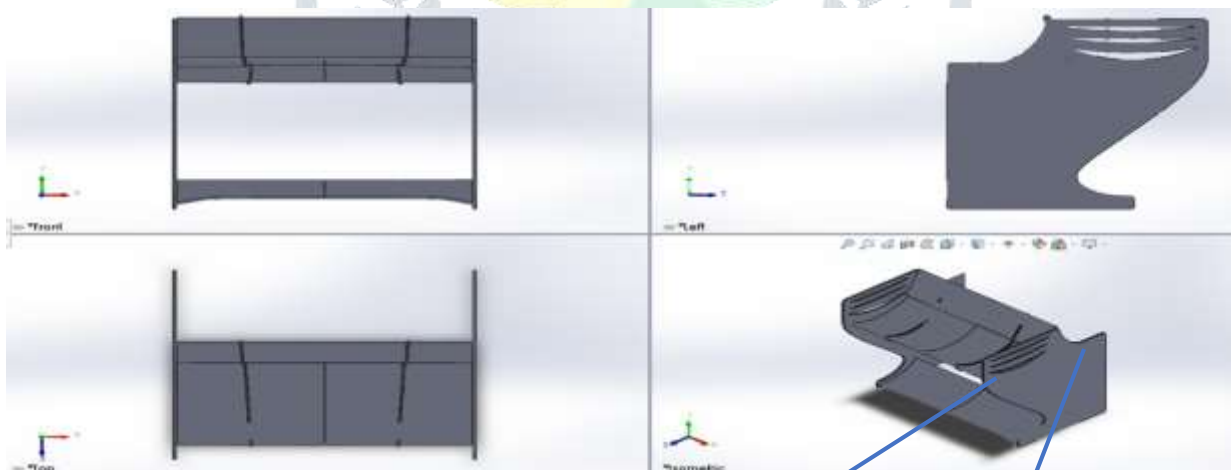


Fig.7 Rear wing



Fig.8 Louvres or gills

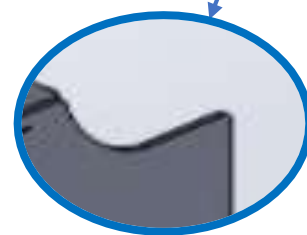


Fig.9 End plate cut out

speed. End plates are used because if wings will be there alone then at their tip vortex formation can take place which increases the drag, so to overcome it endplates are used as cover. But again, due to cover it separates air on the wings

which are at high pressure than free moving air outside the wing which is at low pressure, due to this pressure difference, the formation of wingtip vortices takes place. To overcome this, louvers have been cut out so that air can pass through it and can mix with the outside air and decrease the pressure difference. But again, due to passing through such a narrow cut out it also forms vortices, to cancel the effect of this vortex, an endplate cut out has been provided which also creates a vortex but in opposite direction.

Front wing: This is the first component of the vehicle to come in contact with high-speed moving air, and it is only responsible for deflecting the air where required and where there is not. Its main function is to generate downforce and. The front wing can be modified in various ways according to requirement. Generally, front wing contains numbers of inverted aerofoils cascaded together, deflector vanes, endplate. Again, for further improvement, some extra components are also added like vortex generators, suction elements, strakes, and moving surfaces. Generally, around 35% - 40% of overall downforce is generated by front wing. Here end plates are used to deflect the air streams away from the front tires and also to avoid wingtip vortices. Deflector vanes are also used for the deflection of air streams away from the tires as they can create unnecessary drag. Wing flaps are used to provide the air to radiators for cooling and it also deflects streams to the underfloor and diffuser which are maximum downforce generators. Strakes are used to strengthen the Y250 vortex. Y250 vortex is the vortex formed 250mm away horizontally from the center of the nose cone by the wingtips. Vortex generators are used to generate vortex which is quite useful to avoid flow separation.

Nose wing: This is the inverted aerofoil attached to the nose of the formula one car. It is not very much used for the generation of drag forces but it helps to maintain incoming air streams above and below the upper control arm of the double-wishbone suspension assembly.

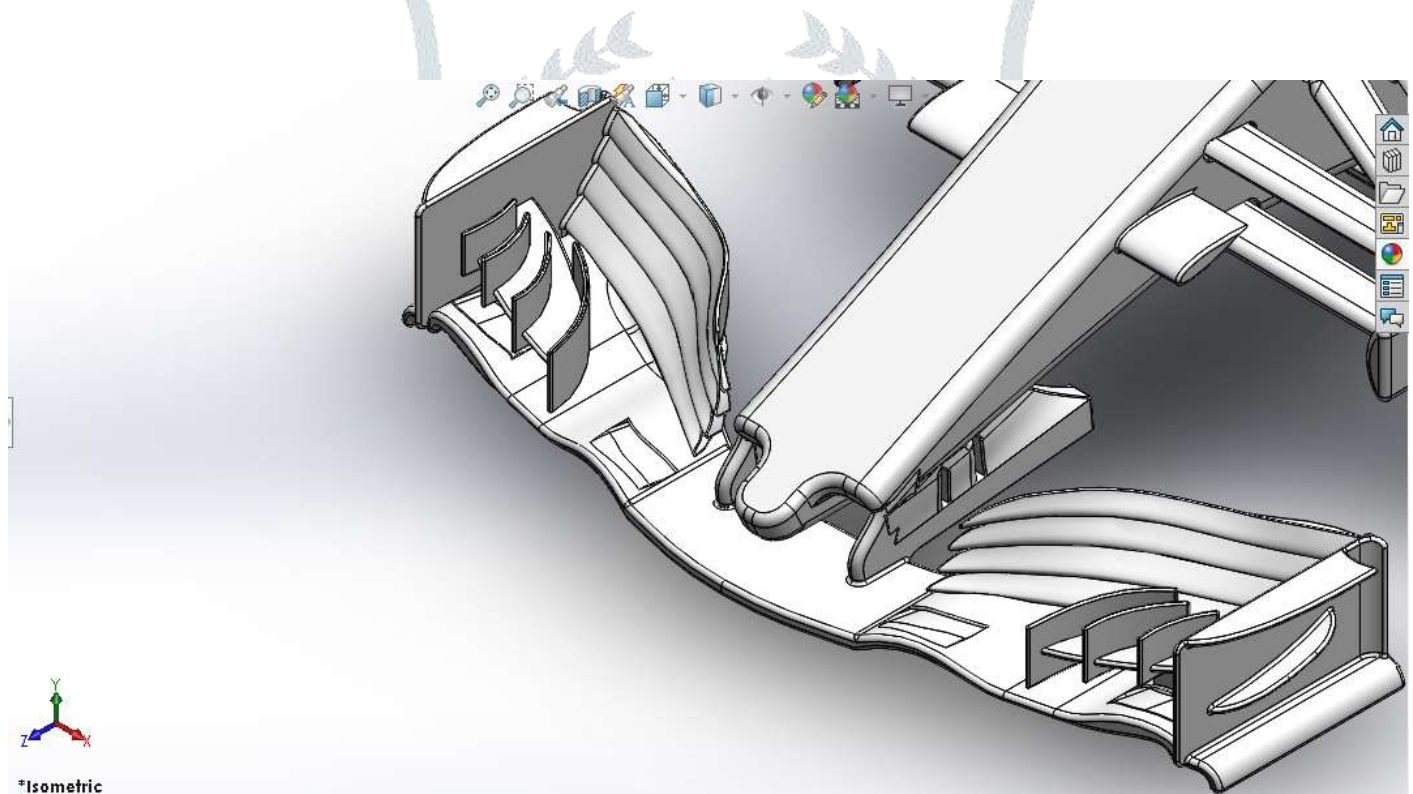


Fig.10 Front wing with deflector vanes and end plate

Nose cone: This is the nose-shaped structure in which the front wing is mounted. These were generally important for the impact protection but with time it is also improved to become more streamlined. These are generally V-shaped for a

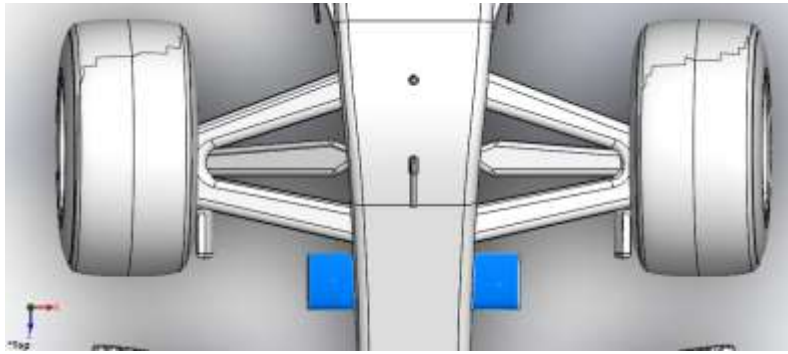


Fig.11 Nose wing

more streamlined body. With further improvement nostrils like opening given to them and incoming air to the nose, cones are further divided and diverted to upper section of nose body and another to the underfloor. The one that is diverted to the upper section of the body is used to prevent the flow separation that is happening above the nose body. This is not that much helpful for the downforce generation but it helps to reduce drag.

Brake duct: This is the opening used in the brakes to cool it. At the time of operation, brake disc temperature may raise

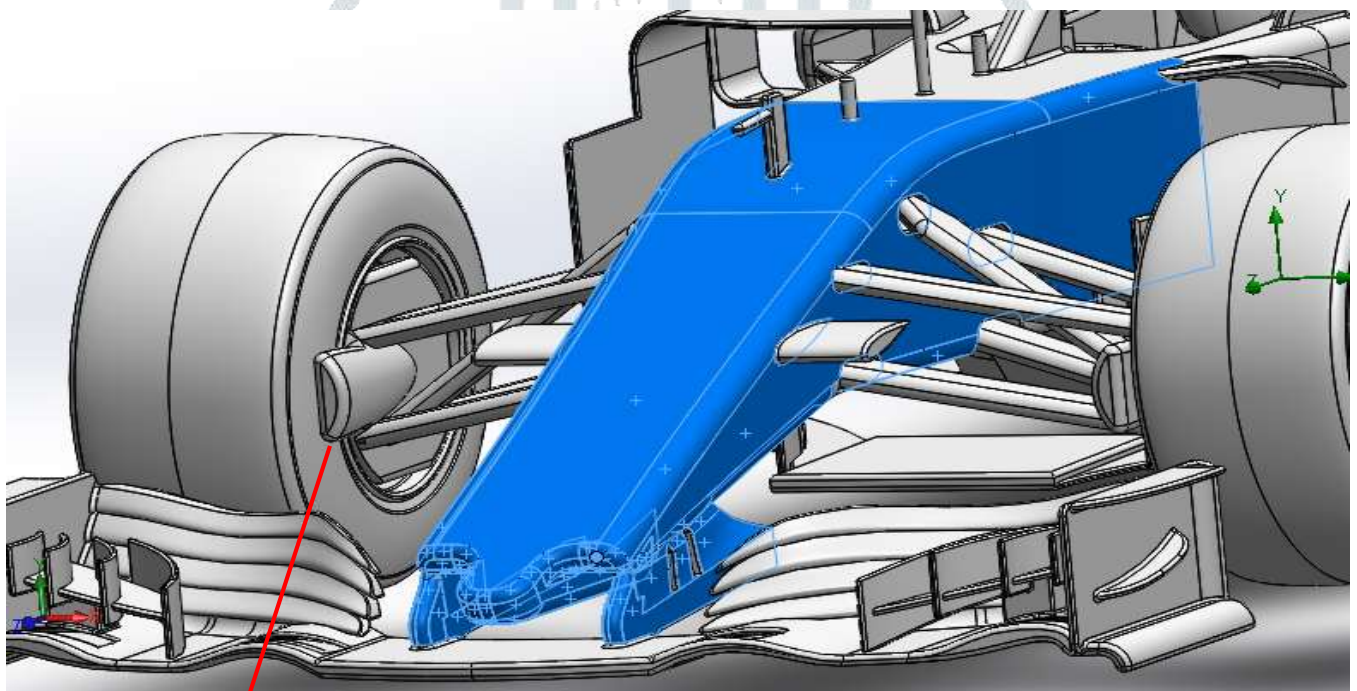


Fig.12 Nose cone

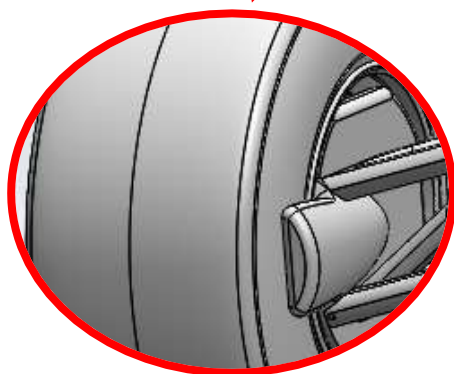


Fig.13 Brake duct

to 1000°C. As the brake discs are carbon disks and can withstand the temperature but this temperature over a prolonged period can cause issues and may affect braking efficiency. Brake ducts divert incoming air over the brake discs to cool it. This increases the brake disc's life and efficiency.

Bargeboard: This is the bodywork on the formula cars behind the suspension arms and between the front wheels and sidepods. Its main function is to deflect the dirty air coming from the wheels with the help of the Y250 vortices. There is also a gap therebetween the bargeboard and body for the clean air coming from the neutral zone of the front wing. That air goes to radiators and boosts the cooling of the engine. It is generally mounted on the extension of the underfloor.

Roof spoiler: Inverted aerofoil-shaped wing placed on top of the engine air intake just above driver's cockpit. Its main function is to generate downforce to balance the force in the middle as the front and rear wing is also generating. It also directs air streams towards the rear wing. It also helps instability by creating a downforce to keep the center of pressure close to the center of gravity.

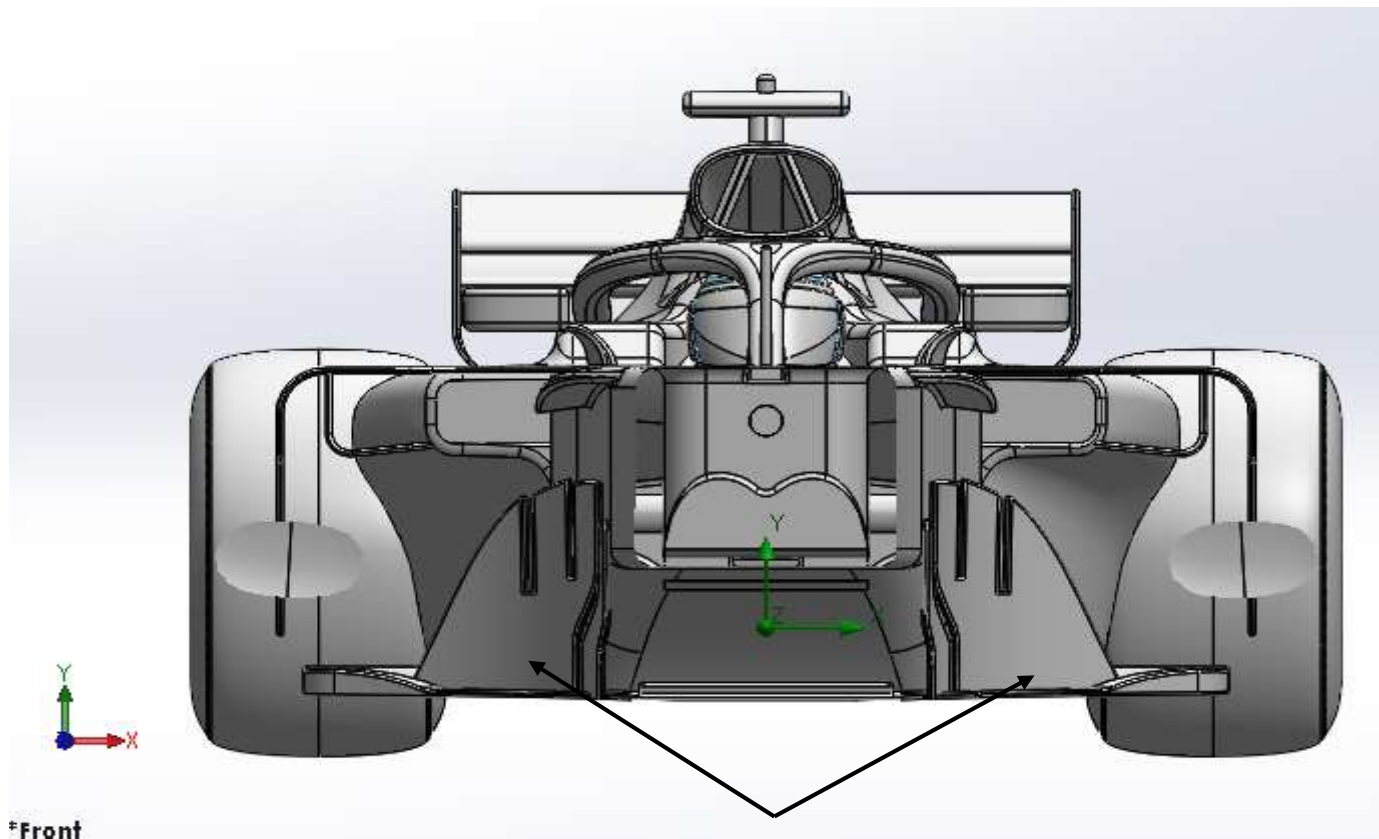


Fig.14 Bargeboard

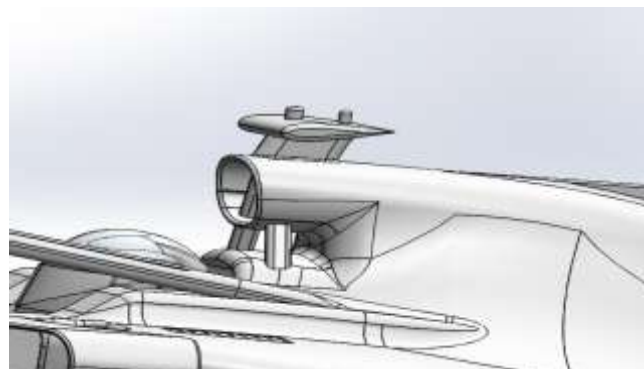


Fig.15 Roof spoiler

Underfloor: This is one of the most critical components of the car's body as it is responsible for 35%-40% of the overall downforce. It creates downforce with the help of the venturi effect. According to FIA regulation under-car, shaping is not allowed but still, many teams use different tricks to increase the efficiency of the underbody. With the help of the bargeboard, it creates vortices in the downward direction, with this way it manages to flush more air downwards. In the lower section of the car step plane and plank is being used to squeeze the passing air and in the back portion of the car, there is a slight upward curve which provides more opening area due to which air accelerates towards it. Due to this acceleration velocity increases and hence lower pressure zone is created below the car which sucks it downwards, thus downward force increases.

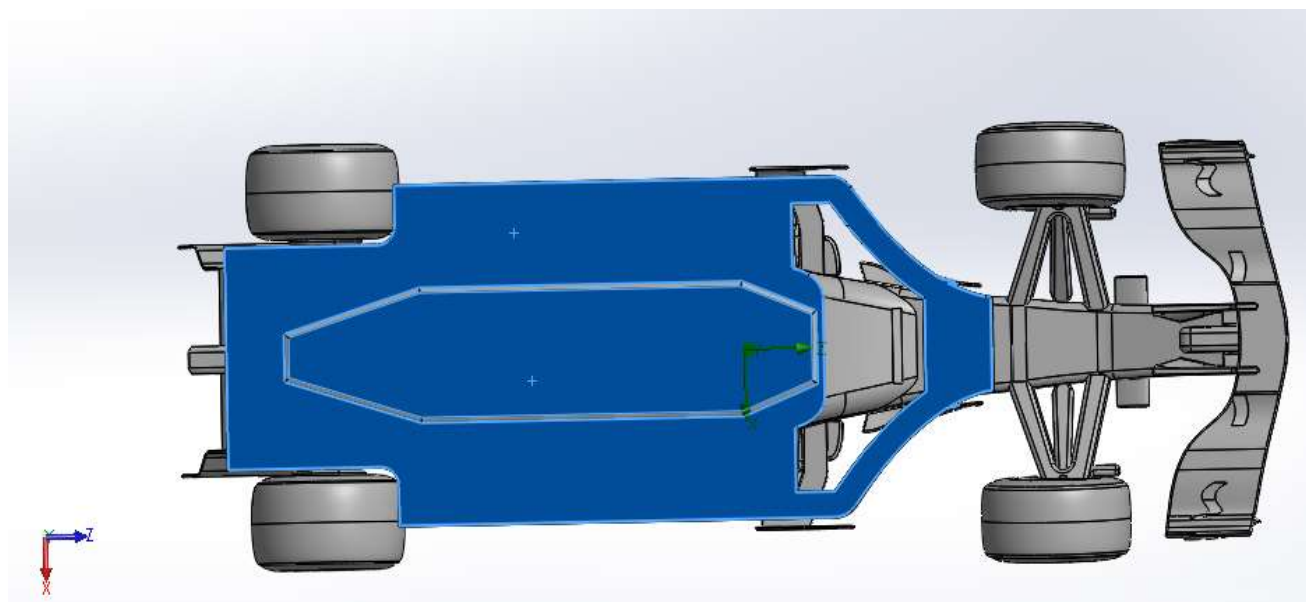


Fig.16 Underfloor and plank

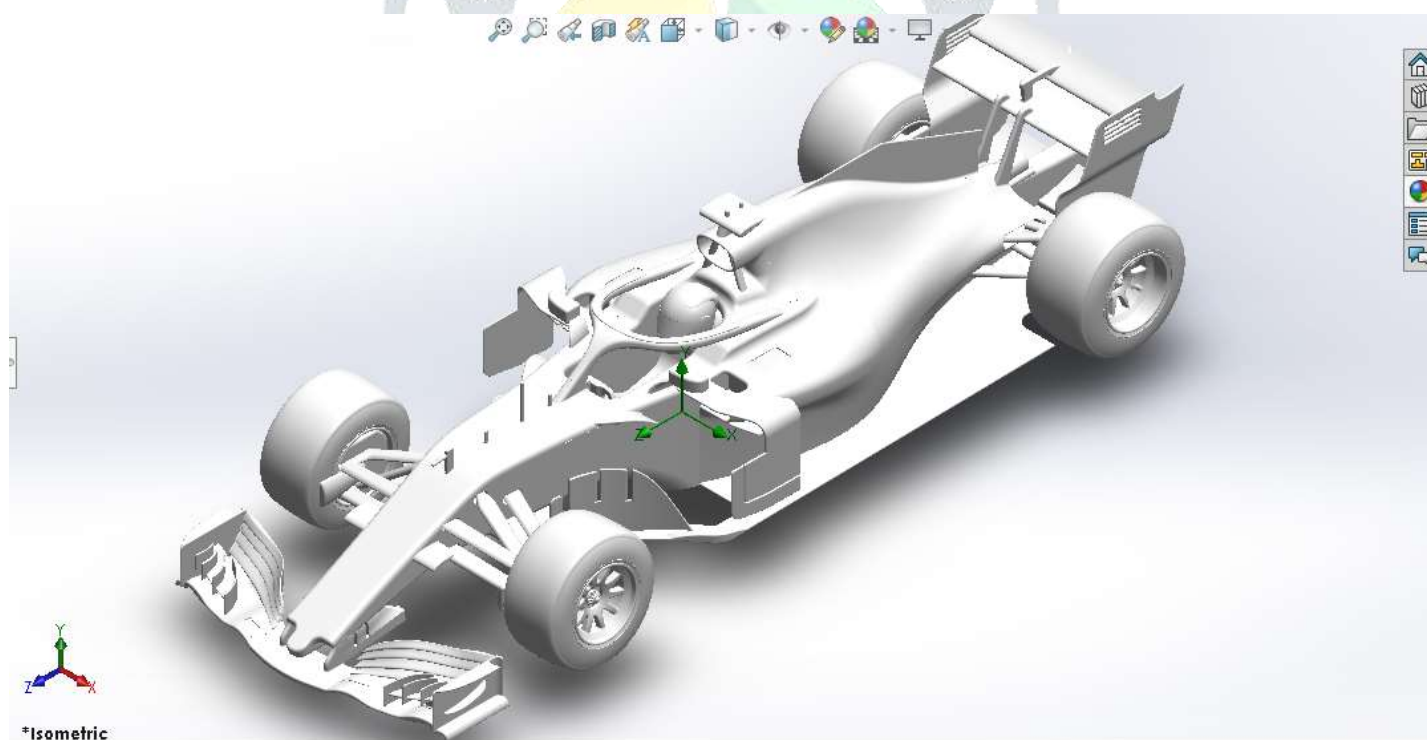


Fig.17 Isometric view of model with all add-ons attached

III. RESULT AND DISCUSSION

The results from the steady-state analysis that has been carried out on the three models of formula one car are discussed in this section. Here the performance of these three models is analyzed in terms of drag and downforce at six different speeds 100, 85, 70, 55, 40, and 25 (meters/sec).

Solver settings and parameters

X min	-0.675 m
X max	0.595 m
Y min	-0.099 m
Y max	0.842 m

Table 3. Computational fluid domain

Z min	-1.420 m
Z max	1.376 m
X size	1.271 m
Y size	0.941 m
Z size	2.795 m

Additional physical calculation options

Heat Transfer Analysis: Heat conduction in solids: Off

Flow Type: Laminar and turbulent

Time-Dependent Analysis: Off

Gravity: On

Radiation: Off

Humidity: Off

Default Wall Roughness: 0 micrometer

Table 4. Ambient Conditions

Thermodynamic parameters	Static Pressure: 101325.00 Pa Temperature: 293.20 K
Velocity parameters	Velocity vector Velocity in X direction: 0 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: -100.000 m/s
Turbulence parameters	Turbulence intensity and length Intensity: 2.00 % Length: 0.007 m

Results

Baseline model without add-ons		
Velocity (m/s)	Drag (N)	Lift (N)
100	365.349501	34.501932
85	187.172931	23.799301
70	98.002711	16.364812
55	65.827193	7.500199
40	31.501863	2.947856
25	8.943671	0.354198

Table 5. Comparison of Drag and Downforce at different speeds for baseline model without add-ons

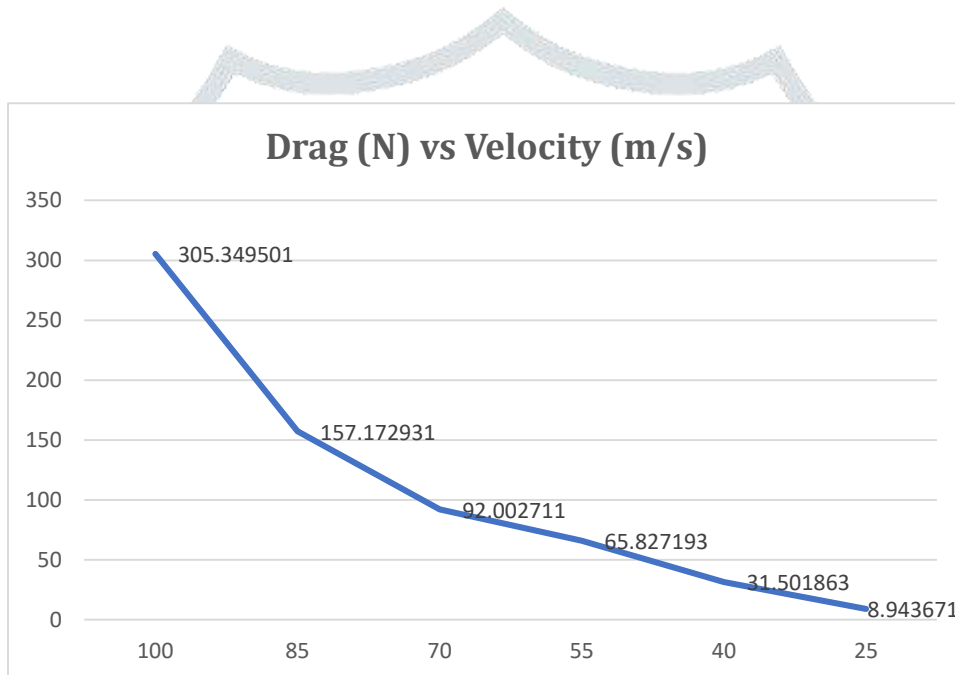


Fig.18 Variation of Drag (N) vs Velocity (m/s)

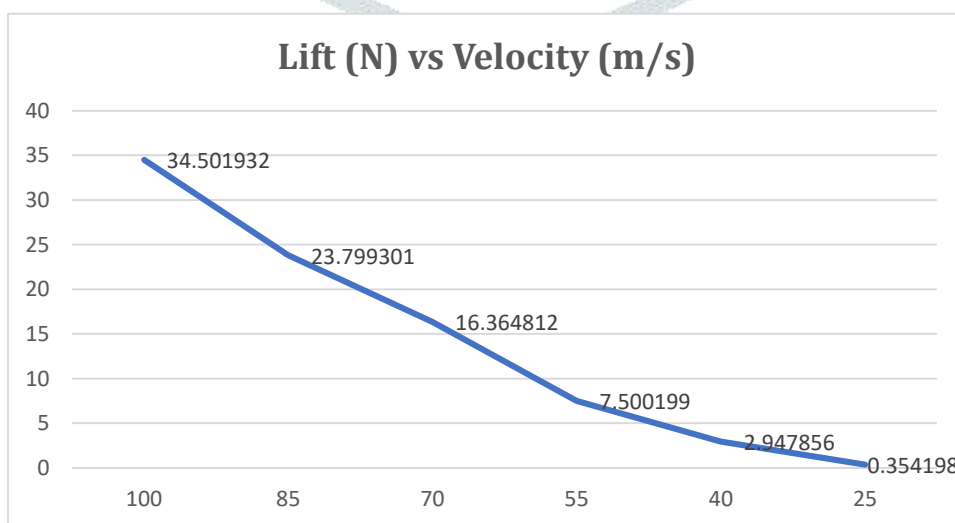


Fig.19 Variation of Lift (N) vs Velocity (m/s)

The next step is to attach the front wing, nose wing, ear wing, top exit, and roof spoiler and then analyze it for the change in downforce and drag. The comparison is shown in tabular form below.

Table 6. Comparison of Drag and Downforce at different speeds for model with front wing, nose wing, ear wing, top exit, and roof spoiler

Model with front wing, nose wing, ear wing, top exit, and roof spoiler		
Velocity (m/s)	Drag (N)	Downforce (N)
100	592.2858289	129.6463173
85	427.1119157	97.03888863
70	290.47945	66.28311686
55	179.0418526	42.78502388
40	94.70806463	22.2006328
25	37.06471509	8.360765448

Drag (Value)

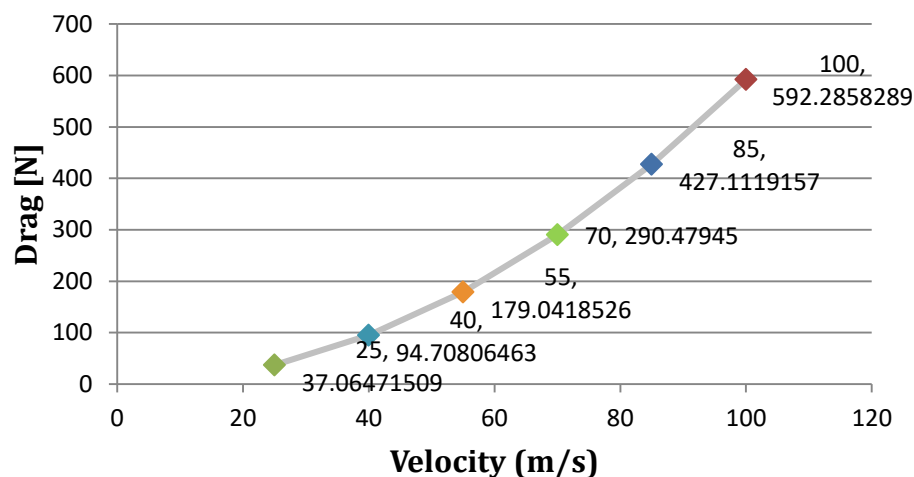


Fig.20 Variation of Drag (N) vs Velocity (m/s)

Downforce (Value)

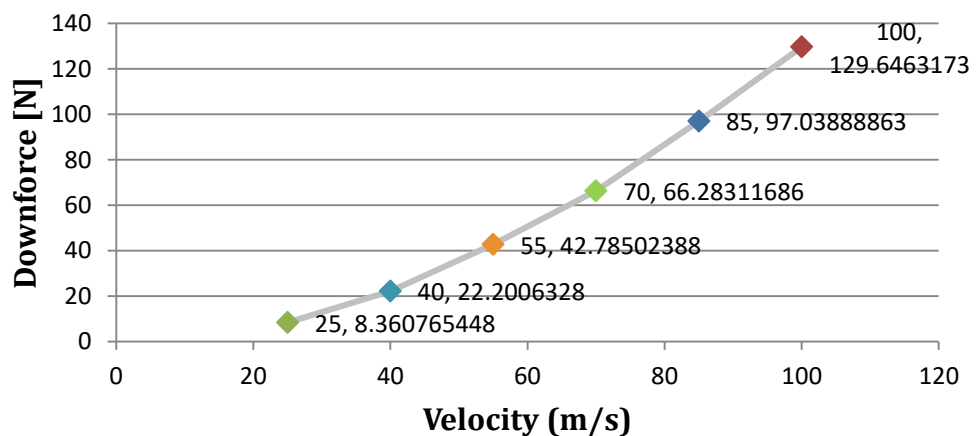


Fig.21 Variation of Lift (N) vs Velocity (m/s)

The velocity isosurface is shown below in fig.22 where it can be seen that the formation of the wake behind the wheels and the car body and also some low-velocity streams on the body.

The model with all add-ons like bargeboard, rear wing, underfloor, diffusor, roof spoiler, nose wing are attached and is analyzed and the result is tabulated below.



Fig.22 Velocity isosurface of model in isometric view

Model with all add-ons attached

Table 7. Comparison of Drag and Downforce at different speeds for model with all add-ons attached

Velocity (m/s)	Drag (N)	Downforce (N)
100	868.1742998	227.2163186
85	630.9287481	169.0764609
70	422.33526	112.468526
55	262.9090186	70.73196783
40	140.6519351	36.11201767
25	54.93230306	13.52118605

Drag (N) vs Velocity (m/s)

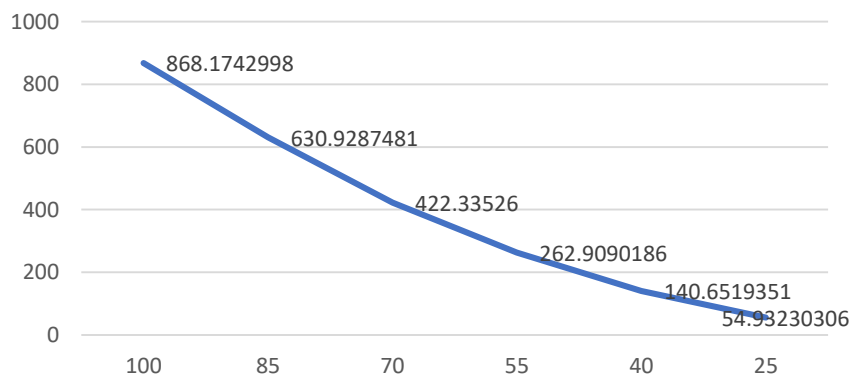


Fig.23 Variation of Drag (N) vs Velocity (m/s)

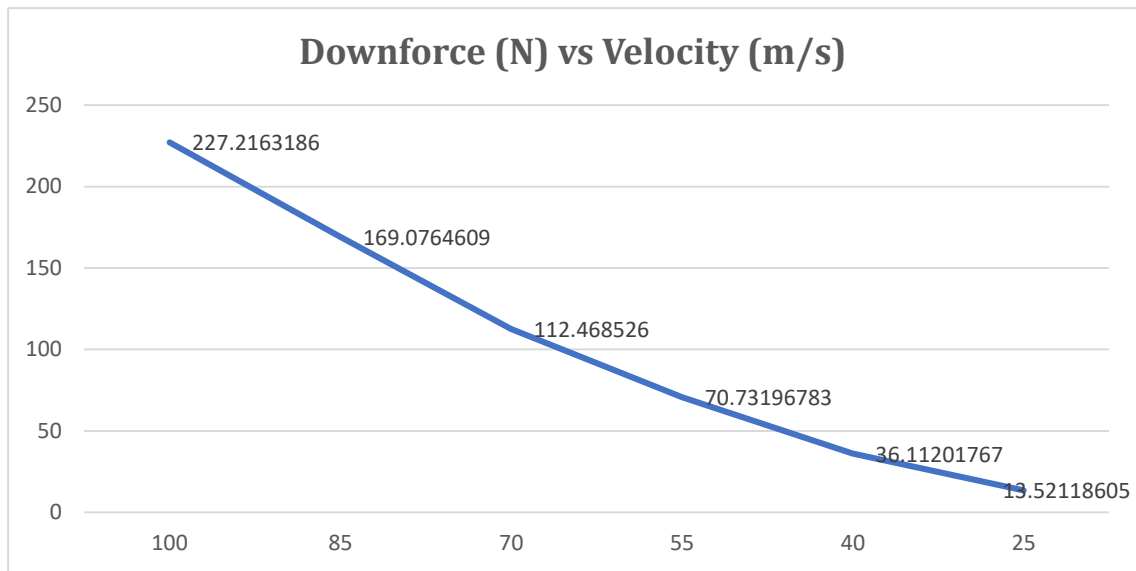


Fig.24 Variation of Downforce (N) vs Velocity (m/s)

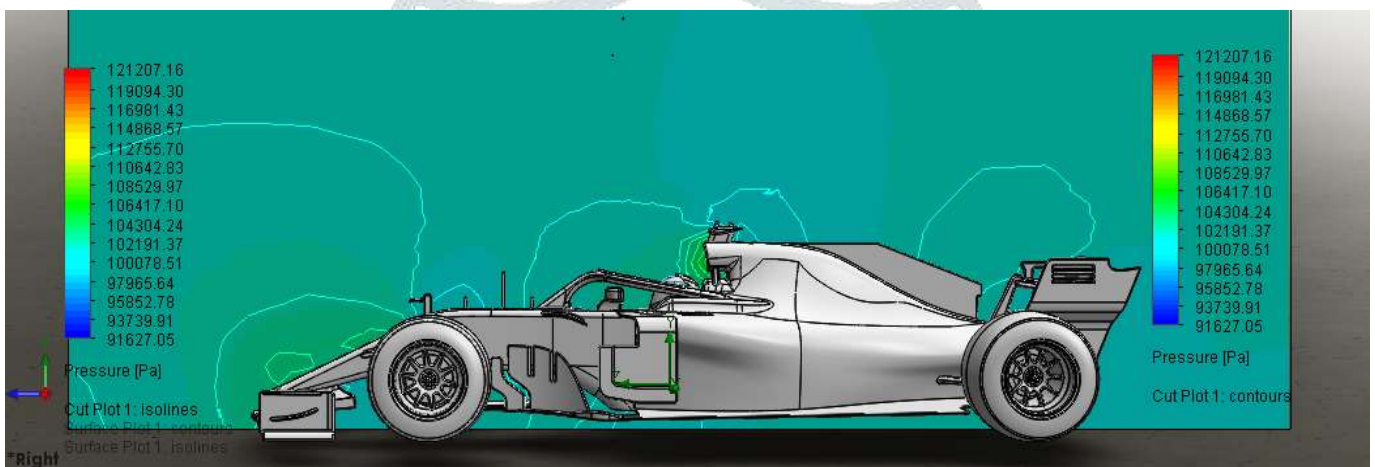


Fig.25 Pressure contour with isolines

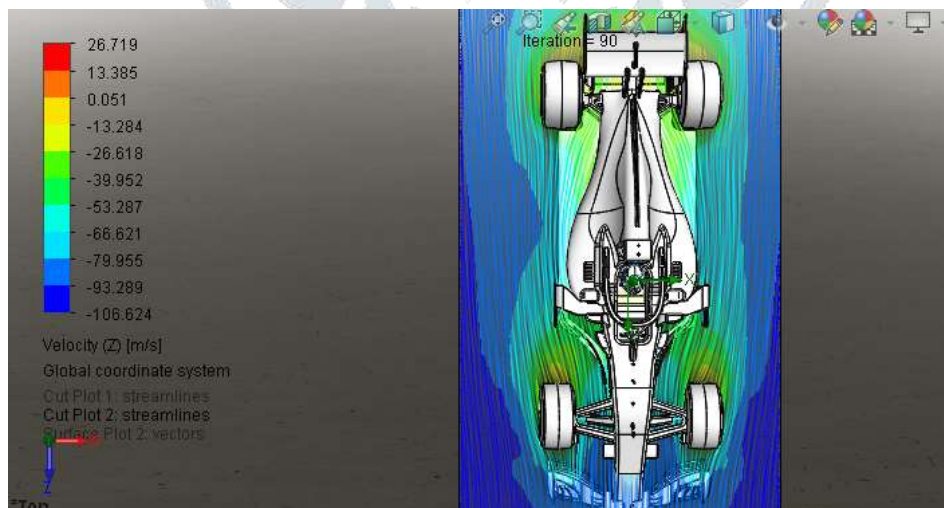


Fig.26 Streamlines and velocity contour

Pressure contour plot on the right plane is shown in fig.25 above. High-pressure zone can be seen on the front wing. In fig. 26 wake region can be seen behind tires and rear wing.

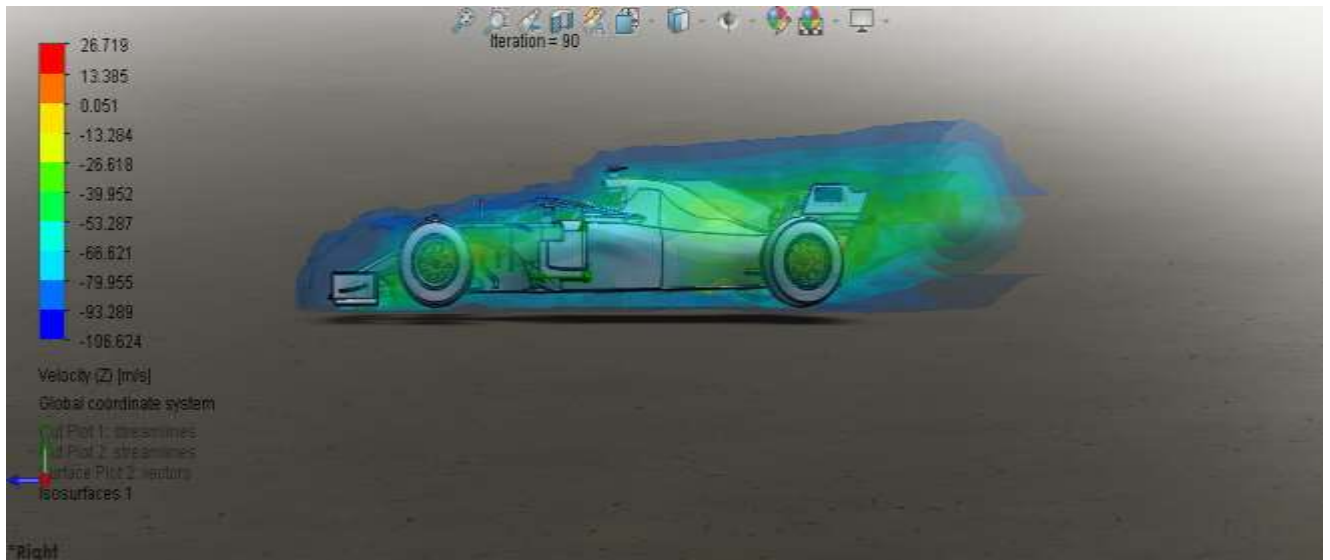


Fig.27 Velocity isosurface in side view

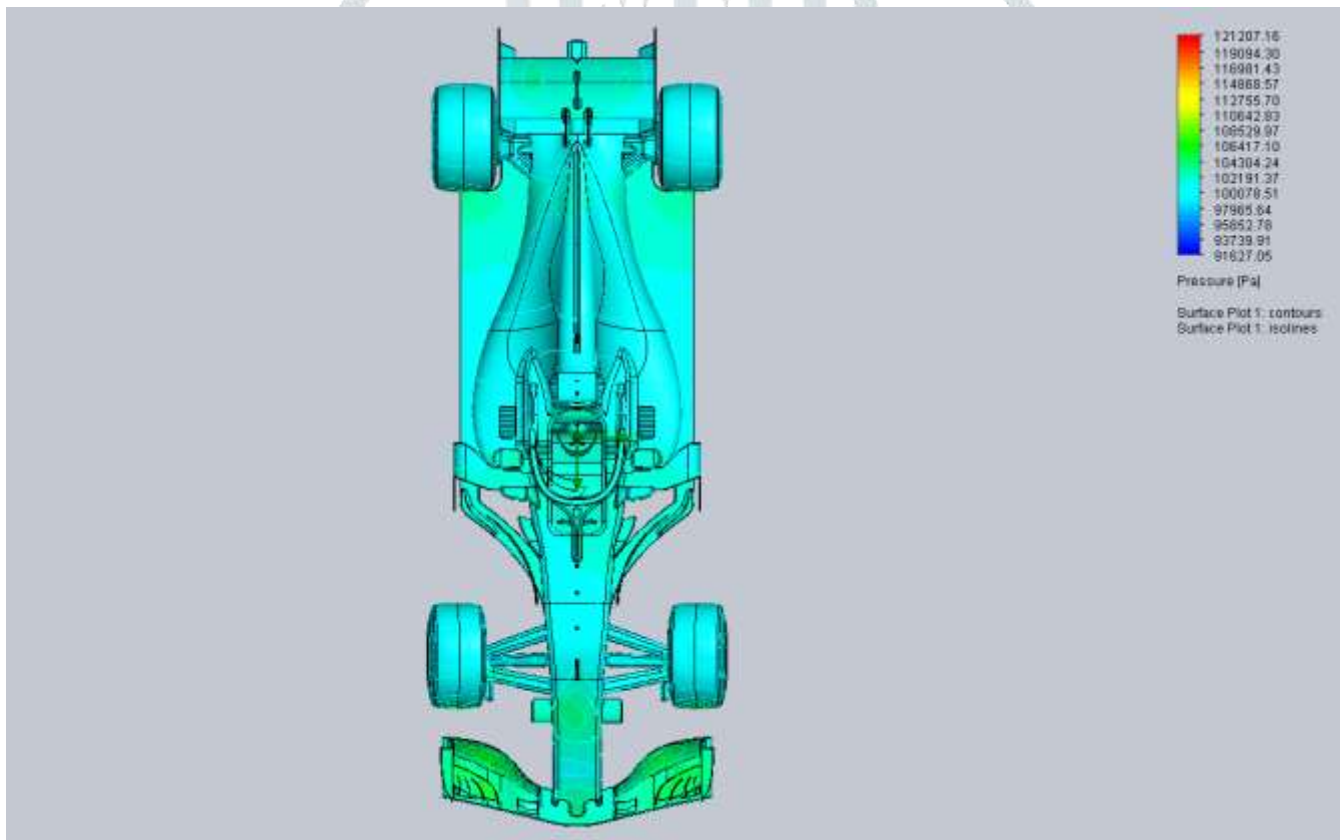


Fig.28 Surface plot for pressure contour in top view

In fig.28 the pressure contour plot, a high-pressure zone can be seen on front and rear wing. In fig. 27 high-velocity streams can be seen below the car which is quite desirable for suction of the vehicle downwards which generates downforce.

IV. COMPARISON OF RESULTS

In the above section, results were discussed for all three cases and variation in drag and downforce is observed. In this section head-on comparison for these parameters is to be done. In graphs and tables baseline will be used for the base model with no add-ons, model with front wing for the model with front wing, nose wing, roof spoiler, ear wing, and top exit, and the model with all add-ons for the model attached with front, rear, ear, nose wing, bargeboard, underfloor, and diffusor. Here results at extreme conditions are discussed i.e., at 100 metres/sec.

Table 8. Comparison of drag and downforces at 100 metres/sec

	Drag (N)	Downforce (N)
Baseline model	365.349501	-34.501932
Model with front wing	592.2858289	129.6463173
Model with all add-ons	868.1742998	227.2163186

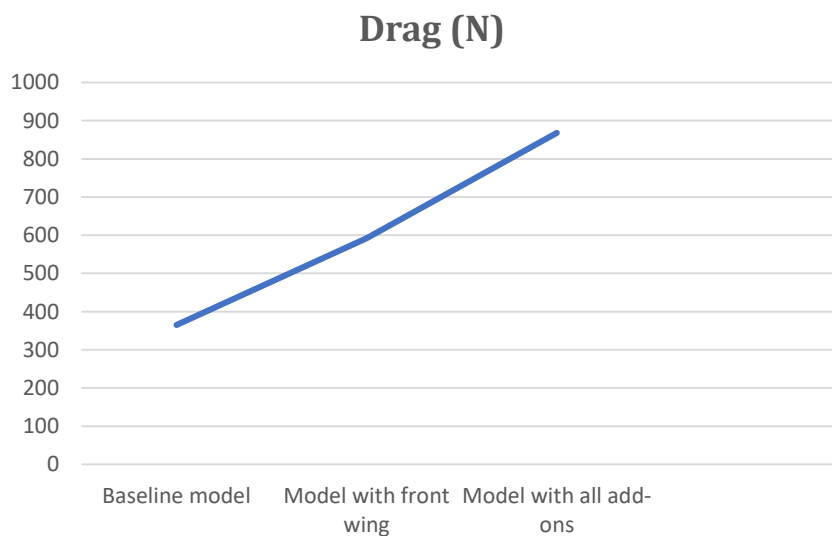


Fig.29 Variation of drag with different models at 100 metres/sec

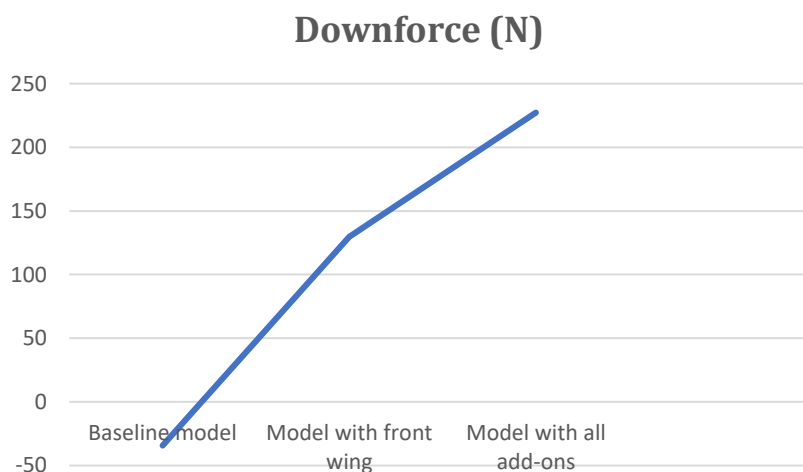


Fig.30 Variation of downforce with different models at 100 metres/sec

V. CONCLUSION

In this paper, the effort has been given to improve the aerodynamic performance of formula one car by adding possible accessories or add-ons following the regulations of FIA (Federation Internationale de Automobile). There have been various add-ons added to the base model like front wing, rear wing, nose wing, ear wing, nose cone, roof spoiler, top exit, bargeboard, brake ducts, deflector vanes, vortex generators, underfloor, and diffusers. In those components too various intricate details have been provided for better efficiency of that particular component like providing louvers and cut out on endplates. After all these additions steady-state CFD analysis has been done and as a result that a comparison has been made between the three models.

From the above results following points can be concluded:

- i. Without any add-ons, instead of downforce, there is a component of lift that is not a good condition for high-speed vehicles like formula one. Due to the lift component, there would not be better traction and hence less stability while turning.
- ii. With the addition of add-ons, drag is also increasing rapidly, since this is obvious as more area is exposed to incoming air but at the expense of that much drag, downforce has increased drastically.
- iii. With the addition of few components in the second model, downforce has increased by 4.76 times and with all add-ons attached it has further increased by ~76%.
- iv. With the addition of only the front wing in the second model, there was a stability issue. As a good amount of downforce generation was there at the front portion and no downforce was being generated in the middle or the back portion, there was unbalance of force.
- v. Without any add-ons, there was no proper distribution of coming air streams to the car's body and this causes unnecessary drag. In the last model, it can be seen the proper circulation of air to the required spaces and flushing away the dirty air from the car's body with the help of additional components and by creating desired vortices.
- vi. Without any add-ons, there was no proper channelling of air streams, due to which it is quite dangerous to be in the wake region of another car.
- vii. Without any add-ons, it is also not possible to overtake another car from a slipstream. As the dirty air from the front car causes less generation of downforce up to 50% which reduces the traction of tires and it is quite difficult to accelerate and overtake in that situation.
- viii. With the observation from the above situation that how different add-ons improve different qualities of the vehicle like bargeboard deflects dirty air from the wheels and directs clean air to the engine radiators which improves cooling, every problem during the actual run of the car can be eliminated by specific add-ons and the right combination of the add-on is very important or unless unnecessary drag will be created.

VI. SCOPE OF IMPROVEMENT

After the analysis, it has been observed that with the addition of all add-ons, downforce was improved but drag was increased in every case. To reduce the drag and even increase the downforce more than before, the above design can be tweaked further. The new design change is also under the FIA regulations.

To reduce the drag the simplest thing that can be done is to reduce the area exposed to incoming stream and make the body more streamlined so that the airflow over the body becomes smoother. Therefore, in order to improve the design instead of bargeboard, a new venturi channel can be used. This venturi channel does not have a large area exposed to incoming air instead it has an opening through which air will pass it and, in the middle, there will be a very narrow space for air streams to pass and at the end, there will be a wide opening due to which air streams will get accelerated and the low-pressure zone will be created there and hence it creates a large amount of downforce without any expense of drag.

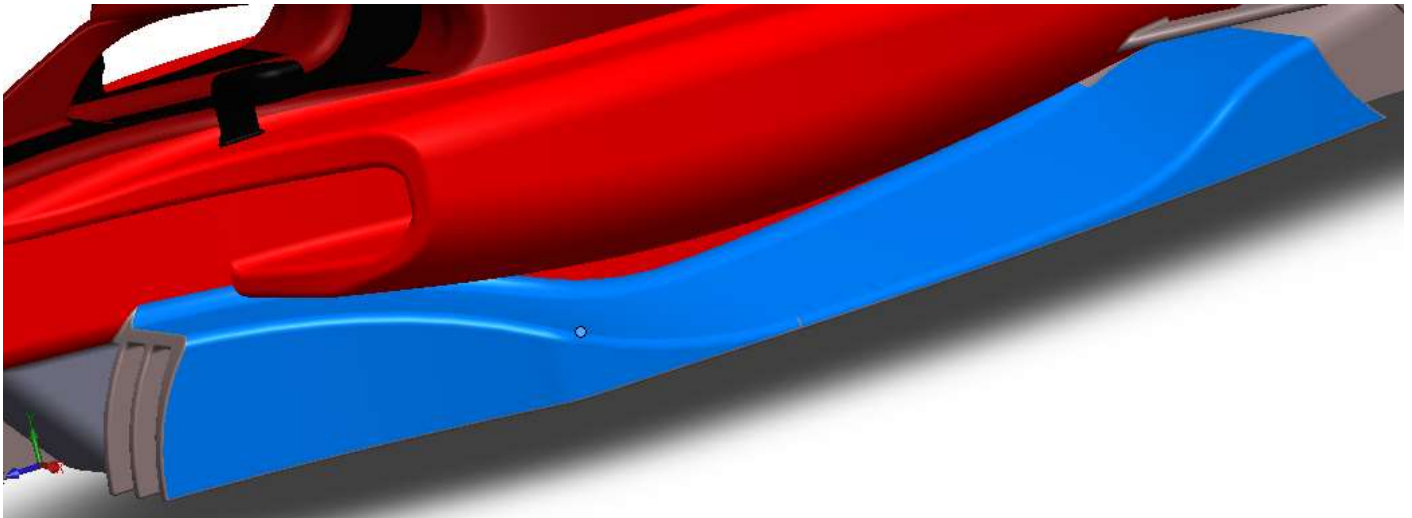


Fig.31 Design of venturi-channel at the place of bargeboard

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